

Review of historical and current research on the Late Cretaceous dinosaurs and dinosaur eggs from Laiyang, Shandong

ZHANG Jia-Liang^{1,2} WANG Qiang¹ JIANG Shun-Xing¹ CHENG Xin¹ LI Ning¹
QIU Rui^{1,2} ZHANG Xin-Jun^{1,2} WANG Xiao-Lin^{1,2*}

(1 Key Laboratory of Vertebrate Evolution and Human Origins of Chinese Academy of Sciences, Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences Beijing 100044

* Corresponding author: wangxiaolin@ivpp.ac.cn)

(2 University of Chinese Academy of Sciences Beijing 100049)

Abstract Here we briefly review the history of research on the Laiyang dinosaur and dinosaur egg faunas, summarize the contributions of C. C. Young and other elder paleontologists to the discoveries of the Late Cretaceous dinosaurs and dinosaur eggs from Laiyang, and introduce the new discoveries and the advances in the research on the Laiyang faunas. The new investigations in Laiyang from 2008 have found a series of valley developed in plain and more than ten new dinosaur or dinosaur egg fossil beds. In 2010, we began the massive excavations at two localities in Jingangkou and collected abundant dinosaurs and other vertebrate fossils, such as a new saurolophine, some theropod material and a new taxon of turtle egg. The bone beds in Locality 2 with the typical sedimentary and burial patterns of mudflow, and these fossil deposits are interpreted as having been carried and deposited by mudflow. The re-observation and the CT scanning data of the crest of *Tsintaosaurus spinorhinus* (IVPP V 725) show that the crest is fractured and solid. However, based on the re-observations of its cranial and postcranial specimens, we consider that *Tsintaosaurus spinorhinus* is a valid taxon of lambeosaurines, which have the hollow crest. Therefore, the crest of *Tsintaosaurus* might not belong to the skull of this individual, and the true form of the crest needs to be confirmed in the future work. We reassess the three species of *Taninus*, and obtain several results. 1) *Taninus sinensis* and *Taninus chingkankouensis* are the valid species of *Taninus*; 2) *Taninus laiyangensis* is invalid.; 3) the sacrum and ilium of *Taninus chingkankouensis* with typical hadrosaurid features should not be referred to *Taninus*.

Key words Laiyang, Shandong; Upper Cretaceous; Wangshi Group; Hadrosauroidea; dinosaur egg

Citation Zhang J L, Wang Q, Jiang S X et al., 2017. Review of historical and current research on the Late Cretaceous dinosaurs and dinosaur eggs from Laiyang, Shandong. *Vertebrata Palasiatica*, 55(2): 187–200

1 Introduction

Laiyang is located in the center of the Jiaodong Peninsula, and the well-developed

国家自然科学基金(批准号: 41172018, 41572020)、国家自然科学基金基础科学中心项目(编号: 41688103)、国家自然科学基金重大项目(编号: 91514302)、中国科学院战略性先导科技专项(B类)(编号: XDB18000000)、国家重点基础研究发展计划项目(编号: 2012CB821900)、国家杰出青年科学基金(编号: 40825005)和莱阳市政府合作项目资助。

收稿日期: 2017-03-08

terrestrial strata around Laiyang belong to the Lower Cretaceous Laiyang and Qingshan groups and the Upper Cretaceous Wangshi Group. The age of these strata ranges from 130 Ma to 70 Ma (Wang et al., 2010, 2012). The Laiyang Group consists primarily of grey and grey-green shales that were deposited in lacustrine environments. Abundant fossils have been recovered from the Laiyang Group, including plants, insects, conchostracans, various other invertebrates, and dinosaur tracks (Chow, 1923; Grabau, 1923; Hong and Wang, 1990; Zhang, 1992; Young, 1960; Li and Zhang, 2000, 2001). The Qingshan Group consists mainly of volcanic rocks interbedded with sedimentary rocks (Liu et al., 2011), and contains the ceratopsian dinosaur *Psittacosaurus* (Young, 1958; Zhao, 1962), pterosaurs (Young, 1958; Zhou, 2010), and the turtle *Peishanemys* (Chow, 1954a). The fossil assemblage in the Laiyang and Qingshan groups is similar to the Jehol Biota, and forms the Laiyang Jehol Biota (Wang et al. 2010). The Upper Cretaceous Wangshi Group mainly comprises fluvial and lacustrine red and gray-green siltstones and mudstones interbedded with gray and gray-green glutenites and siltstones, and is divided from bottom to top into the Xingezhuang, Jiangjunding, Jingangkou and Changwangpu formations (Hu et al., 2001), the last of which was thought to occur only in Zhucheng and to be absent in Laiyang (Wang et al. 2012). The Jiangjunding and Jingangkou formations contain rich concentrations of hadrosauroid bones, coexisting with abundant other vertebrate bones and dinosaur eggs. More recently, Yan and Chen (2005) obtained an isotope age of 73 Ma for the Jingangkou Formation (which they called the Hongtuya Formation) based on a basalt sample from the town of Daxizhuang in Jiaozhou City. The dinosaurs and dinosaur eggs in the Wangshi Group form the Laiyang Hadrosauroid Fauna and Dinosaur Egg Fauna. Laiyang is also among the relatively few areas worldwide that are rich in both dinosaur bones and dinosaur eggs.

The earliest discoveries on dinosaur bones and dinosaur eggs in Laiyang can be traced back to the 1920s, and a golden age of exploration of the fauna took place in the 1950s. It was from Laiyang that Chinese geologists and paleontologists first reported a fossil assemblage containing Chinese dinosaurs, dinosaur eggs, pterosaurs, insects and plants (Wang et al., 2010). Because of these discoveries, the Society of Vertebrate Paleontology of China was founded in 1984 in Laiyang. In 1951, an IVPP expedition team led by C. C. Young undertook a series of massive prospecting trips and excavations in Laiyang (Liu, 1951; Young, 1958) and found abundant vertebrate fossils including multiple specimens of the lambeosaurine hadrosaurid *Tsintaosaurus spinorhinus*, the first reasonably complete dinosaurian skeleton after the establishment of P. R. China (Young, 1958). These discoveries turned Laiyang into a focal point for the study of dinosaur and dinosaur egg fossils in China. Although dinosaurs and dinosaur eggs continued to be found sporadically in Laiyang in the following decades, no large-scale excavations were conducted. Since 2008, however, an IVPP-Laiyang team has carried out annual field activities including massive excavations, at both Young's old quarry (Locality 1) and a new quarry (Locality 2) in Laiyang. During these new field surveys, we have discovered several dinosaur and dinosaur egg localities, and found abundant fossils. Here we briefly review the history of research on the dinosaurs and dinosaur eggs of Laiyang, including the contributions of Young and other paleontologists, and also introduce the new finds and research advances in Laiyang.

2 History of discoveries of dinosaurs and dinosaur eggs in Laiyang

Laiyang is an important source of Late Cretaceous dinosaurs and dinosaur eggs in China. In the last century, C. C. Young, A. Grabau, H. C. Tan, D. S. Liu, M. C. Chow and other geologists and paleontologists conducted a series of field investigations and excavations, and abundant fossils were found, especially of dinosaurs and dinosaur eggs. The history of research on dinosaurs from Laiyang can be generally divided into three periods.

2.1 The first period of dinosaur discovery in Laiyang (1920s–1930s)

Tan (1923) reported the presence of dinosaurs, fishes, insects and plants in the Cretaceous strata of Laiyang. Grabau (1923) studied the fishes and insects, while T. H. Chow (1923) studied the plants. The dinosaur material, which had been collected by Tan, is now kept in the palaeontological collections of the Museum of Evolution, Uppsala University, Sweden (PMU). Wiman (1929) described the hadrosauroid material and named it *Tanius sinensis* in Tan's honor. Buffetaut (1995) and Buffetaut and Tong (1995) referred the ankylosaurid material to *Pinacosaurus* cf. *grangeri*. Poropat and Kear (2013) reassessed some theropod material. In addition, H. S. Wang (1930) subsequently reported some dinosaurs from Jingangkou.

2.2 The second period of dinosaur discovery in Laiyang (1950s–1970s)

In 1950, L. H. Wang and K. Y. Kwan from the Department of Geology and Mineralogy, University of Shandong collected some dinosaurs and dinosaur eggs from the Upper Cretaceous strata around Laiyang (Chow, 1951). These specimens are now kept in the Museum of Geology at Jilin University and were reported on by Chow (1951), who identified them as hadrosaurid with Young's help.

Young attached great importance to these discoveries. In 1951, he led a field expedition to Laiyang in which D. S. Liu and C. Y. Wang also participated. This team carried out massive excavations at Jingangkou (Wangshi Group) and Doushan (Qingshan Group), digging out abundant dinosaurs and dinosaur eggs (Liu, 1951; Young, 1958). Liu (1951) reported in detail on the field investigations and excavations. Young (1954) studied the dinosaur eggs and divided them into two categories: short eggs (*Oolithes spheroides*) and long eggs (*Oolithes elongates*), proposed the preliminary classification of dinosaur eggs based on this scheme. Chow (1954b) described the microstructure of dinosaur eggshell. These early studies helped to lay the methodological and nomenclatural foundation for subsequent research on dinosaur eggs. In addition, Chow (1954a) studied the turtle fossils collected in 1951.

Young established the species *Tsintaosaurus spinorhinus* based on a complete composite skeleton and additional bones from the Wangshi Group in a monograph entitled “The Dinosaurian Remains of Laiyang, Shantung”, which was an important monograph about dinosaurs produced in the early stages of P. R. China. (Young, 1958) (Fig. 1). The book also reported other dinosaurs collected from the Wangshi Group, including a new species of *Tanius* (*Tanius chingkankouensis*), theropods (cf. *Szechuanosaurus campi* and *Chinkankousaurus fragilis*), and some fractured bones referred to stegosaurs and sauropods (Young, 1958). These

dinosaur finds revealed the basic contours of the Laiyang Hadrosauroid Fauna (Young, 1958). Young also reported *Psittacosaurus sinensis* and some pterosaur bones from the Qingshan Group (Young, 1958), and it was the first report of pterosaurs from China.



Fig. 1 Restoration of *Tsintaosaurus spinorhinus*

Dinosaurs reported from Laiyang after this publication included another species of *Tanius*, *T. laiyangensis* (Zhen, 1976) and a pachycephalosaurid, *Micropachycephalosaurus hongtuyanensis* (Dong, 1978). In addition, there was another hadrosaurid, *Shantungosaurus giganteus* found from Zhucheng and Laiyang (Hu, 1973; Hu et al., 2001).

In the 1970s, Z. K. Zhao further studied the microstructure of dinosaur eggs, erecting the two oofamilies Elongatoolithidae and Spheroolithidae based on Young and Chow's work (Zhao and Jiang, 1974; Zhao, 1975, 1979), he was also the first to propose the current international classification of dinosaur eggs (Zhao and Jiang, 1974; Zhao, 1979).

2.3 The third period of dinosaur discovery in Laiyang (from 2008)

Since 2008, the IVPP-Laiyang expedition team has carried out a series of field investigations in Laiyang. These investigations have revealed sets of valleys that interrupt the plains that dominate the landscape and more than ten dinosaur bone and egg sites have been found in the valleys. In 2010, the team undertook massive excavations at Locality 1 (Young's old *Tsintaosaurus* quarry) and Locality 2 (a new quarry), and collected abundant dinosaur bones. Abundant science bases and geoparks have been founded in the field area, such as the Laiyang National Geopark, a National Key Protected Fossil Locality, a Field Observation Base of the Ministry of Land and Resources, etc.

3 Laiyang Hadrosauroid Fauna and Dinosaur Egg Fauna

Since the 1920s, abundant dinosaur bones and other fossils have been found in Cretaceous strata around Laiyang form three important Cretaceous faunas: the Laiyang Jehol Fauna, the Laiyang Hadrosauroid Fauna, and the Laiyang Dinosaur Egg Fauna.

3.1 Laiyang Hadrosauroid Fauna

The Laiyang Hadrosauroid Fauna represented by *Tsintaosaurus* and *Taninus* is one of the most important and famous Late Cretaceous dinosaur faunas in China. Up to now, members of seven major reptile clades have been reported (Wiman, 1929; Young, 1958; Hu, 1973; Zhen, 1976; Dong, 1978; Buffetaut and Tong, 1995; Poropat and Kear, 2013). Of the seven clades, nine species in eight genera have been named (Wang et al., 2010) (Table 1), and other unnamed members represent stegosaurs, sauropods and theropods (Young, 1958; Poropat and Kear, 2013).

Hadrosauroids consist of some basal forms, known as non-hadrosaurid hadrosauroids, and the monophyletic Hadrosauridae (Prieto-Márquez, 2010). Many hadrosaurid species have hypertrophied nasal passages associated with cranial crests, which vary widely in morphology and are important in hadrosaurid taxonomy (Ostrom, 1962, Hopson, 1975). Hadrosauridae is divided into two main clades: the flat-headed or solid-crested Saurolophinae, and the hollow-crested Lambeosaurinae (Horner et al. 2004). In recent phylogenetic analyses, *Taninus* has been recovered as a non-hadrosaurid hadrosauroid, whereas *Tsintaosaurus* and *Shantungosaurus* have been placed in Hadrosauridae as a lambeosaurine and a saurolophine respectively (Prieto-Márquez, 2010; Zhang and Wang, 2012).

Table 1 Laiyang Hadrosauroid Fauna

Hadrosauroidae	<i>Tsintaosaurus spinorhinus</i> Young, 1958 <i>Taninus sinensis</i> Wiman, 1929 <i>Taninus chingkankouensis</i> Young, 1958 <i>Taninus laiyangensis</i> Zhen, 1976 <i>Shantungosaurus giganteus</i> Hu, 1973
Ankylosauridae	<i>Pinacosaurus</i> cf. <i>P. grangeri</i> Buffetaut & Tong, 1995
Pachycephalosauridae	<i>Micropachycephalosaurus hongtuyanensis</i> Dong, 1978
Theropoda	cf. <i>Szechuanosaurus campi</i> Young, 1958 <i>Chinkankousaurus fragilis</i> Young, 1958
Testudines	<i>Glyptops</i> sp. Chow, 1954a

3.2 Laiyang Dinosaur Egg Fauna

Abundant dinosaur eggs were collected at the same time with the dinosaur body fossils. To date, four oofamilies, five oogenera, and eleven oospecies have been reported, forming the Laiyang Dinosaur Egg Fauna (Wang et al., 2010) (Table 2).

Table 2 Laiyang Dinosaur Egg Fauna

Elongatoolithidae	<i>Elongatoolithus elongatus</i> Young, 1965 <i>Elongatoolithus andrewi</i> Zhao, 1975
Ovaloolithidae	<i>Ovaloolithus chinkangkouensis</i> Zhao, 1979 <i>Ovaloolithus monostriatus</i> Zhao, 1979 <i>Ovaloolithus tristriatus</i> Zhao, 1979 <i>Ovaloolithus mixtistriatus</i> Zhao, 1979 <i>Ovaloolithus laminadermus</i> Zhao, 1979
Spheroolithidae	<i>Spheroolithus chiangchiungtingensis</i> Zhao, 1979 <i>?Spheroolithus megadermus</i> Zhao, 1979 <i>Paraspheroolithus irenensis</i> Zhao, 1979
Dictyoolithidae	<i>Protodictyoolithus jiangi</i> Liu & Zhao, 2004

chinaXiv:201711.01905v1

4 New fossil discoveries in Laiyang

During the recent fieldwork in the Wangshi Group, several valleys were discovered in Jingangkou and Jiangjunding, and are considered to form “the Laiyang Dinosaur Valley Series”, where more than ten dinosaur bone and egg sites have been found (Fig. 2). The dinosaur valleys generally trend nearly SN or EW, and some intersect.



Fig. 2 Dinosaur valley interrupting the topography of the plains in Laiyang

4.1 Re-excavation of Young's old *Tsintaosaurus* quarry (Locality 1) and the discovery of a new turtle egg

In 2010, the IVPP-Laiyang expedition team confirmed the location of the quarry where Young found *Tsintaosaurus* in 1951 (Locality 1), and also reopened the quarry for further excavation. The bone-bearing beds were identified, and several isolated bones of hadrosauroids and other vertebrates were found in this site. Among these fossils, a single elongated egg is the most noteworthy. The microstructure of the egg shell is different from which seen in the egg shell of dinosaurs, birds or crocodiles. This specimen was identified as a new type of turtle egg and named *Emydoolithus laiyangensis* (Wang et al., 2013a).

4.2 Excavations and new discoveries in Locality 2

Locality 2 is in the east part of Jingangkou Village, 1 km east of Locality 1, and represents an exposure of the middle part of the Wangshi Group (Wang et al., 2012). Eight layers bearing dinosaur bones occur in a thickness of 100 m, five of them have been excavated in recently years. An on-site museum has been built in the western part of the excavation area.

The first and second fossil-bearing layers are composed of gray-green silty mudstone containing black bones. They are actually parts of a single original layer, but movement along a fault separated them. The fossils in the first layer are mainly big theropod and hadrosauroid

bones, and are similar to those found at the bottom of the second layer. In the middle of the second layer, big complete bones and small rounded bone fragments are mixed together, whereas the fossils in the upper part of the layer are all fractured and rounded small bones. The third, fourth and fifth layers mainly consist of siltstones, and the fossils in these layers are white in color. The excavations carried out in recent years have targeted the third layer, which is 1.5–1.8 m thick, and contains abundant hadrosauroid bones in a normally graded vertical sequence. Near the top of this layer are small vertebrae and fractured bones, and near the bottom are big isolated bones, some of which are articulated. Abundant hadrosauroid and other vertebrate bones are found in the fourth layer, and several complete large turtle fossils in the fifth layer.

The strata at Locality 2 are interpreted to have been mainly formed by mudflow events, because they show the typical sedimentary and taphonomic characteristics expected for mudflow deposits: mudstones and siltstones with some poorly-sorted gravel, most of the bones are isolate, the large and small complete bones are mixed in the bottom of the layers, the long axes of the bones lack a consistent orientation, and a few bones are oblique or vertical in orientation. The taphonomy of the bones shows that a group of live hadrosauroids was engulfed and torn apart by a sudden flood and mudflow, and the carcasses were carried a short distance, and rapidly buried. However, abundant fractured and rounded small bones and plant fragments indicate these fossils were reworked before the final bury. Thousands of hadrosaurid bones exposed in recent years represent at least 20–30 individuals. These can be divided into three size classes, which are tentatively assumed to adult, subadult, and late juvenile individuals, according to the studies of ontogenetic changes in the hadrosaurid *Maiasaura peeblesorum* by Horner et al. (2000). Some of the hadrosauroid bones are referred to Saurolophinae on the basis of the maxilla with a anterodorsal process, the jugal with a long anteroposteriorly rostral process and a shallow embayment, and the distal end of the ischial shaft without the “foot-like” process (Prieto-Márquez, 2008, 2010). These saurolophine material are belong to a new genus and species, *Laiyangosaurus youngi* in Young’s honor, based on the following autapomorphies: a prominent and narrow ridge on the lateral side of the nasal, a slightly posteriorly deflected primary ridge of the maxillary tooth, a dorsolateroposteriorly recurved retroarticular process of the surangular, a relatively shallow and rostr dorsally directed caudal margin of the lacrimal process of the jugal, the posterior margin of the maxilla facet limited by a rostr dorsally-oriented narrow ridge, and orbital margins that are wider than the infratemporal margins of the jugal (Zhang et al. 2017). In addition, other hadrosauroid bones would be referred to *Tsintaosaurus spinorhinus* (Lambeosaurinae) on the basis of the humerus with a long and wide deltopectoral crest, and the ilium with a deep central plate (Young, 1958; Prieto-Márquez, 2008, 2010; Zhang, 2013).

5 Recent advances in the study of dinosaurs and dinosaur eggs from Laiyang

5.1 Validity of *Tsintaosaurus spinorhinus* and CT scanning of its crest

Young (1958) described *Tsintaosaurus spinorhinus* based on a nearly complete composite skeleton (IVPP V 725), a separate incomplete skull (IVPP V 818), and additional postcranial

materials from the Wangshi Group west of Jingangkou Village, Laiyang. *T. spinorhinus* has a rodlike, anterodorsally projected cranial crest, which consists of the nasal bones and terminates in two branches (Fig. 3). This feature differs from the posterodorsally projected crests of other lambeosaurines, which incorporate both the nasals and the premaxillae (Ostrom, 1960; Hopson, 1975; Horner, 2004; Evans et al., 2009). Since *T. spinorhinus* was reported in 1958, it has been the subject of considerable controversy, especially with regard to its crest. Some scholars have even doubted the validity of the taxon (Rozhdestvensky, 1977; Taquet, 1991; Horner and Weisharnpel, 1990). while some researchers believed that *T. spinorhinus* was assignable to Lambeosaurinae and most likely hollow crested, based on the presence of lambeosaurine features in the skull and postcranial bones (Maryńska and Osmólska, 1981; Brett-Surman, 1989; Buffetaut and Tong, 1993, 1995). Horner et al. (2004) confirmed that *T. spinorhinus* was a basal lambeosaurine through phylogenetic analysis. Prieto-Márquez and Wagner (2013) restored *T. spinorhinus* with a hollow posterodorsally projected crest as in typical lambeosaurines, based on the skull and some additional bone fragments.

Recently, we used the CT scanner to scan the crest of *Tsintaosaurus* (IVPP V 725), and to reconstruct its internal structure (Zhang and Wang, 2012). Notably, the fracture on the root of the crest is severe. There are only several small bone fragments between the crest and the skull. The fracture surfaces on the root of the crest do not match those of the skull (Fig. 3D, E) (Zhang and Wang, 2012). Therefore, it is doubtful that the morphology of the crest of *Tsintaosaurus* is real.

The cross-section of the crest shows that there are three parts along the sagittal plane (Fig. 3C). The middle part is a rectangular, long strip in our 3D-reconstruction. The two lateral parts do not enclose a cavity around the middle part, but instead sandwich the middle part between them. Therefore, the crest of *Tsintaosaurus* could not enclose a nasal cavity, which is divided into a pair of hollow passage in the crest of all the other lambeosaurines. In addition, the middle part of the crest of *Tsintaosaurus* is also part of the skeleton, and the crest would be solid, not hollow.

However, based on our observations of the skull and postcranial bones of *Tsintaosaurus*, we consider the descriptions of the other parts of *Tsintaosaurus* by Young and other researchers to be reliable and accurate (Young, 1958; Buffetaut and Tong, 1993, 1995). *Tsintaosaurus* exhibits a series of characteristics of Lambeosaurinae, including the frontal being completely excluded from the orbital margin, the upward doming on the dorsal part of the frontal, the width being greater than the length of the supratemporal fenestra, the parietal sagittal crest being relatively short and down-curved, the anterodorsal process absent in the anterior of the maxilla, the dorsal process of the maxilla being posterodorsally extended, the symphyseal process of the dentary being medioventrally extended, the quadrate being relatively curved, and the distal region of the ischial shaft being ventrally expanded, forming a large “boot-like” process (Horner et al., 2004; Prieto-Márquez, 2008, 2010).

In conclusion, *Tsintaosaurus* is a valid lambeosaurine taxon, but the crest we examined does not appear to be the real one of *Tsintaosaurus*, or even the material might possibly not belong to the skull of this individual. However, the anterior part of its frontal and prefrontal

both extend dorsally to support the crest. Given that morphology, *Tsintaosaurus* should have a hollow up-extended crest, as the other lambeosaurines. However, future work will have to confirm the true form of the crest.

5.2 Validity of three species of *Tanios*

Three species have been placed in the genus *Tanios* (*T. sinensis*, *T. chingkankouensis*, and *T. laiyangensis*). Only the type species, *T. sinensis*, has a partial skull (Wiman, 1929), and the other two species are known only from postcranial skeletons (Young, 1958, Zhen, 1976). Therefore, the validity of *T. chingkankouensis* and *T. laiyangensis* was doubted by Buffetaut and Tong (1993, 1995). Horner et al. (2004) suggested that *T. chingkankouensis* is a valid taxon, and that *T. laiyangensis* is a synonym of *T. chingkankouensis*.

Tanios sinensis was collected in 1923 from the Jiangjunding Formation, Wangshi Group stratigraphically below the Jingangkou Formation, where *Tsintaosaurus* were found (Tan, 1923; Wiman, 1929). *T. sinensis* was described as a flat hadrosaurid based on a nearly complete skull (Fig. 4) and some postcranial bones (Wiman, 1929). Recently, it was referred to a valid taxon of basal hadrosauroid with a series of basal hadrosauroid features, such as the presence of the rostral process of the jugal relatively shallow dorsoventrally, the posterodorsal border of the rostral process bearing a remarkable horizontally oriented ridge and continuing to the dorsal border of the rostral process (making a deep concave maxilla facet in the medial surface of the rostral process), and the apex of the supraacetabular process located caudodorsal to the caudal tuberosity of the ischial peduncle (Horner et al., 2004; Prieto-Márquez, 2008, 2010).

Young (1958) erected *T. chingkankouensis* based on a few postcranial bones collected in the same excavation with *Tsintaosaurus spinorhins* at Jingangkou, Laiyang. Buffetaut and Tong (1993, 1995) considered that the ilium of *T. chingkankouensis* shows advanced hadrosaurid features. The ilium of *T. chingkankouensis* displays a characteristic of saurolophines (Prieto-Márquez, 2008, 2010), in that the apex of the supraacetabular process is located anterodorsal

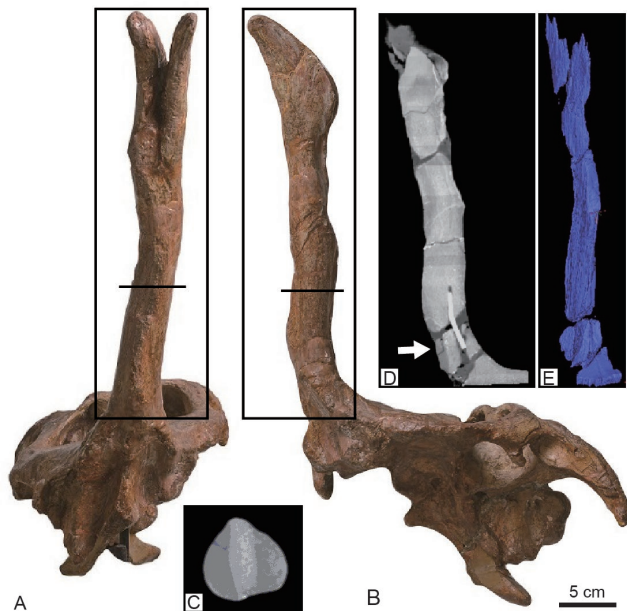


Fig. 3 Photographs and CT scan of the crest of *Tsintaosaurus spinorhinus* (IVPP V 725)

A–B. skull roof in anterior (A) and lateral (B) view; C. cross section through the crest (at the position indicated by a line in A, B); D. sagittal section through the crest (the part in the frame in A, B, and the white arrow in D shows the fracture on the root of the crest); E. 3D reconstruction of the morphology of the hollow within the crest (the part in the frame in A, B)

(modified from Zhang and Wang., 2012)

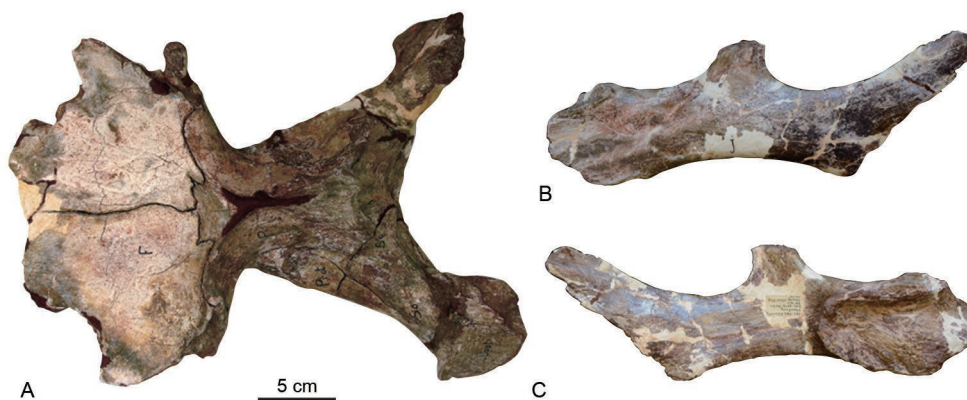


Fig. 4 Braincase and jugal of *Tanuis sinensis* (PMU 24720)

A. braincase in dorsal view; B–C. left jugal in lateral (B) and dorsal (C) views

to the caudal tuberosity of the ischial peduncle (Fig. 5). In addition, whether the sacra with a longitudinal ventral furrow belong to *T. chingkankouensis* is questionable, because the recent research suggests that the presence or absence of that ventral sacral furrow varies within species (Prieto-Márquez, 2008). Therefore, this character would not be diagnostic of *T. chingkankouensis*. However, *T. chingkankouensis* has a slightly inflated distal end of the ischium (Young, 1958), and that morphology is a characteristic of basal hadrosauroids (Prieto-Márquez, 2008, 2010). In addition, *T. chingkankouensis* has the parallel dorsal and ventral margins of the distal blade of the scapula, which is similar with *T. sinensis*, but the more straight dorsal margins of the scapula is different from *T. sinensis* (Young, 1958). Therefore, *T. chingkankouensis* is a valid taxon of *Tanuis*, but the ilium would not belong to *Tanuis*, and there are some questions about its sacrum that will require further study.

T. laiyangensis was assigned to *Tanuis* based on a broken ischium and a sacrum with a ventral furrow, similar to *T. chingkankouensis*, collected from the same site as *Tsintaosaurus*

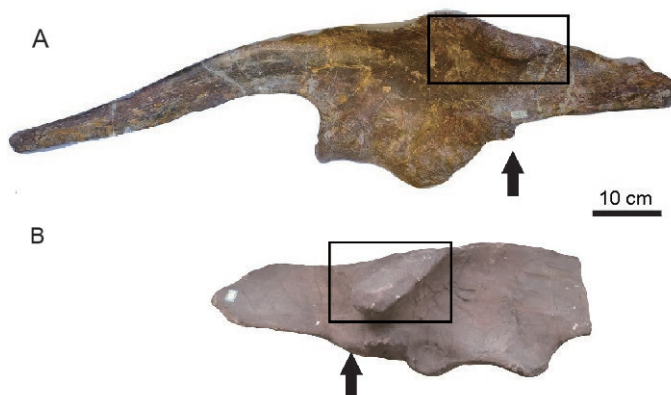


Fig. 5 Comparison between the ilia of *Tanuis sinensis* and *T. chingkankouensis* in lateral view

A. left ilium of *T. sinensis* (PMU 24720); B. right ilium of *T. chingkankouensis* (IVPP V 724)

spinorhinus and *T. chingkankouensis* (Zhen, 1976). Zhen (1976) considered that the number of the vertebrae of sacrum in *T. laiyangensis* is more than *T. chingkankouensis*. However, the presence or absence of furrow and the number of the sacral are not diagnostic (Prieto-Márquez, 2008, 2010). Therefore, *T. laiyangensis* is likely not a valid taxon.

5.3 Advances in *Shantungosaurus giganteus*

Shantungosaurus giganteus was described as a giant flat-head saurolophine, based on a nearly complete composite skeleton collected from Wangshi Group, in Longgujian, Zhucheng, Shandong (Hu, 1973; Hu et al., 2001). There are also a few specimens of *S. giganteus* found in Laiyang (Hu et al., 2001). Another two large hadrosaurids, *Zhuchengosaurus maximus* (Zhao et al., 2007) and *Huaxiaosaurus aigahtens* (Zhao et al., 2011), were reported from Zhucheng, which were considered synonyms of *S. giganteus* (Ji et al., 2011; Hone et al., 2014).

5.4 Advances in dinosaur eggs from Laiyang

Liu et al. (2013) compared dinosaur eggs collected in Laiyang, Shandong Province and Changtu, Liaoning Province, and referred the eggs in Changtu to *Spheroolithus spheroides* (Young, 1954; Zhao, 1979) and *S. megadermus* (Young and Wang, 1959; Zhao, 1979), which were known only from Laiyang in prior reports. The dictyoolithid eggs are widely distributed in China, and they are the important members of the Laiyang Dinosaur Egg Fauna. Wang et al. (2013b) re-examined the holotypes of the four oospecies of Dictyoolithidae, and determined that only *Dictyoolithus hongpoensis* was valid in the oogenus *Dictyoolithus*. They established a new oogenus *Protodictyoolithus*, and placed *D. jiangi* (Liu and Zhao, 2004) from the Laiyang Basin in *Protodictyoolithus* (Wang et al., 2013b).

These new discoveries and advances in recent years have enriched the diversity of the Laiyang Hadrosauroid Fauna and Dinosaur Egg Fauna. With further excavation and fossil preparation, more discoveries will be made in the future.

Acknowledgements We thank Li Yan, Xiang Long, Gao Wei, Zhou Hongjiao, Wang Ruijie, Meng Xi, Pan Rui, Xu Dan, Wang Wenhao, Shou Huaquan, Liu Xinzheng, Zhang Jie and Wang Ping (IVPP) for excavating and preparing the specimens. We also thank Yang Guoqiang, Li Shenggang, Zou Changhou, Lu Mengxuan, Gai Xinzhong, Lan Hong, Wang Yan, Zhang Weihua, Sun Yu, Zhao Yuting, Li Wenbin, Li Jian and Wang Jianhua (Laiyang) for supporting our excavations. We also thank Dr. Corwin Sullivan and Dr. Tom Stidham (IVPP) and two reviewers for their valuable comments and English correction on the manuscript. We thank Zhao Chuang for drawing the restoration of *Tsintaosaurus spinorhinus*. This study was supported by the National Natural Science Foundation of China (41172018, 41572020, 41688103), the Major Research Plan of the National Natural Science Foundation of China (91514302), the Strategic Priority Research Program (B) of the Chinese Academy of Sciences (XDB18030504), the National Key Basic Research Program of China (2012CB821900), the National Science Fund for Distinguished Young Scholars (40825005), and the Laiyang Government Cooperation Dinosaur Project.

山东莱阳晚白垩世恐龙与恐龙蛋研究历史和新进展

张嘉良^{1,2} 王 强¹ 蒋顺兴¹ 程 心¹ 李 宁¹ 裘 锐^{1,2} 张鑫俊^{1,2} 汪筱林^{1,2}

(1 中国科学院古脊椎动物与古人类研究所, 中国科学院脊椎动物演化与人类起源重点实验室 北京 100044)

(2 中国科学院大学 北京 100049)

摘要: 简要回顾了莱阳恐龙和恐龙蛋化石群的研究历史和以杨钟健为代表的老一代地质古生物学者对莱阳恐龙和恐龙蛋研究发现的杰出贡献, 并介绍了莱阳恐龙和恐龙蛋的最新发现和若干研究进展。在近年来对莱阳周边地层进行的大规模考察中, 发现了一系列发育在平原上的恐龙峡谷群, 以及其中蕴含的十几个恐龙和恐龙蛋新地点和新层位。2010年开始, 在对莱阳金岗口村附近的2个化石地点的发掘中, 发现了以鸭嘴龙科为主的大量脊椎动物化石和蛋化石, 包括一类新的栉龙亚科成员, 一些大型兽脚类恐龙化石, 以及一新的龟鳖类蛋化石等。2号地点化石富集层具有典型的泥石流沉积特征和骨骼埋藏特征。对棘鼻青岛龙的特殊头饰进行了CT扫描和三维重建, 发现其头饰是实心结构, 但其他骨骼特征证明棘鼻青岛龙属于具有头饰的赖氏龙亚科是确定无疑的, 所以目前发现的头饰应不是其真实状态或根本不属于其头部骨骼。此外, 对谭氏龙1属3种的重新观察研究得出以下结论: 中国谭氏龙和金刚口谭氏龙应是有效属种, 但部分骨骼还有疑问, 还需要进一步研究, 而莱阳谭氏龙为无效属种。

关键词: 山东莱阳, 上白垩统, 王氏群, 鸭嘴龙超科, 恐龙蛋

中图法分类号: Q915.864 **文献标识码:** A **文章编号:** 1000-3118(2017)02-0187-14

References

- Brett-Surman M K, 1989. A revision of the Hadrosauridae (Reptilia: Ornithischia) and their evolution during the Campanian and Maastrichtian. Ph.D thesis. Washington, D.C: George Washington University. 1-272
- Buffetaut E, 1995. An ankylosaurid dinosaur from the Upper Cretaceous of Shandong (China). *Geol Mag*, 132(6): 683-692
- Buffetaut E, Tong H Y, 1993. *Tsintaosaurus spinorhinus* Young and *Tanais sinensis* Wiman: a preliminary comparative study of two hadrosaurs (Dinosauria) from the Upper Cretaceous of China. *C R Acad Sci Ser II*, 317: 1255-1261
- Buffetaut E, Tong H Y, 1995. The Late Cretaceous dinosaurs of Shandong, China: old finds and new interpretations. In: Sun A L, Wang Y Q eds. Sixth Symposium on Mesozoic Terrestrial Ecosystems and Biota. Beijing: China Ocean Press. 139-142
- Chao T K, Chiang Y K, 1974. Microscopic studies on the dinosaurian eggshells from Laiyang, Shandong Province. *Sci Sin*, 17(1): 73-90
- Chow M C, 1951. Notes on the Late Cretaceous dinosaurian remains and the fossil eggs from Laiyang, Shantung. *Bull Geol Soc China*, 31: 89-96
- Chow M C, 1954a. Cretaceous turtles from Laiyang, Shantung. *Acta Palaeontol Sin*, 2(4): 395-408
- Chow M C, 1954b. Additional notes on the microstructure of the supposed dinosaurian eggshells from Laiyang, Shantung. *Acta Palaeontol Sin*, 2(4): 389-394

- Chow T H, 1923. A preliminary note on some younger Mesozoic plants from Shantung. *Bull Geol Surv China*, 5(2): 81–141
- Dong Z M, 1978. A new genus of *Pachycephalosauria* from Laiyang, Shantung. *Vert PalAsiat*, 16(4): 225–228
- Evans D C, Ridgely R, Witmer L M, 2009. Endocranial anatomy of lambeosaurine hadrosaurids (Dinosauria: Ornithischia): a sensorineural perspective on cranial crest function. *Anat Rec*, 292(9): 1315–1337
- Grabau A W, 1923. Cretaceous fossils from Shantung. *Bull Geol Surv China*, 5(2): 143–182
- Hone D W E, Sullivan C, Zhao Q et al., 2014. Body size distribution in a death assemblage of a colossal hadrosaurid from the Upper Cretaceous of Zhucheng, Shandong Province, China. *Hadrosaurs*. In: Eberth D A, Evans D C eds. *Hadrosaurs*. Bloomington: Indiana University Press. 524–531
- Hong Y C, Wang W L, 1990. Insects fossil from the Laiyang Basin, Shandong Province. In: the Regional Geological Surveying Team, Shandong Bureau of Geology and Mineral Resources eds. *The Stratigraphy and Palaeontology of Laiyang Basin, Shandong Province*. Beijing: Geological Publishing House. 44–189
- Horner J R, Weishampel D B, 1990. *Hadrosauridae*. In: Weishampel D B, Dodson P, Osmólska H eds. *The Dinosauria*. Berkeley: University of California Press. 534–561
- Horner J R, Ricqlès S A D E, Padian K, 2000. Long bone histology of the hadrosaurid dinosaur *Maiasaura peeblesorum*: Growth dynamics and physiology based on an ontogenetic series of skeletal elements. *J Vert Paleont*, 20: 115–129
- Horner J R, Weishampel D B, Forster C A, 2004. *Hadrosauridae*. In: Weishampel D B, Dodson P, Osmólska H eds. *The Dinosauria*, 2nd ed. Berkeley: University of California Press. 438–463
- Hopson J A, 1975. The evolution of cranial display structures in hadrosaurian dinosaurs. *Paleobiology*, 1: 21–43
- Hu C Z, 1973. A new hadrosaur from the Cretaceous of Zhucheng, Shantung. *Acta Geol Sin*, 2: 179–202
- Hu C Z, Cheng Z W, Feng X S, 2001. *Shantungosaurus giganteus*. Beijing: Geological Publishing House. 1–216
- Ji Y N, Wang X, Liu Y et al., 2011. Systematics, behavior and living environment of *Shantungosaurus giganteus* (Dinosauria: Hadrosauridae). *Acta Geol Sin-Engl*, 85: 58–65
- Li R H, Zhang G W, 2000. New dinosaur ichotaxon from the Early Cretaceous Laiyang Group in the Laiyang Basin, Shandong Province. *Geol Rev*, 46(6): 605–610
- Li R H, Zhang G W, 2001. A preliminary study of nonmarine trace fossils from the Laiyang Group (Early Cretaceous), Laiyang Basin, eastern China. *Acta Palaeontol Sin*, 40(2): 252–261
- Liu J Y, Zhao Z K, 2004. A new oospecies of the dinosaur eggs (*Dictyoolithus*) from Laiyang, Shandong Province. *Vert PalAsiat*, 42(2): 166–170
- Liu J Y, Wang Q, Wang X L et al., 2013. A parataxonomic revision of spheroolithid eggs from the Upper Cretaceous Quantou Formation in Changtu, Liaoning. *Vert PalAsiat*, 51(4): 278–288
- Liu T S, 1951. Discovery process of dinosaur and egg fossils in Shandong, Laiyang. *Chin Sci Bull*, 2: 1157–1162
- Liu Y Q, Kuang H W, Peng N et al., 2011. Sedimentary facies of dinosaur trackways and bonebeds in the Cretaceous Jiaolai Basin, eastern Shandong, China, and their paleogeographical implications. *Earth Sci Front*, 18(4): 9–24
- Maryńska T, Osmólska H, 1981. Cranial anatomy of *Saurolophus augustirostris* with comments on the Asian Hadrosauridae (Dinosauria). *Palaeontol Pol*, 42: 5–24
- Ostrom J H, 1962. The cranial crests of hadrosaurian dinosaurs. *Postilla*, 62: 1–29
- Poropat S F, Kear B P, 2013. Reassessment of coelurosaurian (Dinosauria, Theropoda) remains from the Upper Cretaceous Wangshi Group of Shandong Province, China. *Cretaceous Res*, 45: 103–113
- Prieto-Márquez A, 2008. Phylogeny and historical biogeography of hadrosaurid dinosaurs. Ph. D thesis. Tallahassee: Florida State University. 1–936
- Prieto-Márquez A, 2010. Global phylogeny of Hadrosauridae (Dinosauria: Ornithopoda) using parsimony and Bayesian methods. *Zool J Linn Soc*, 159: 435–502

- Prieto-Márquez A, Wagner J R, 2013. The 'unicorn' dinosaur that wasn't: a new reconstruction of the crest of *Tsintaosaurus* and the early evolution of the Lambeosaurine crest and rostrum. *Plos One*, 8(11): 1–20
- Rozhdestvensky A K, 1977. The study of dinosaurs in Asia. *J Palaeont Soc India*, 20: 102–119
- Tan H C, 1923. New research on the Mesozoic and early Tertiary geology in Shantung. *Bull Geol Surv China*, 5(2): 55–79
- Taquet P, 1991. The status of *Tsintaosaurus spinorhinus* Young, 1958 (Dinosauria). *Paleontol Contrib Univ Oslo*, 364: 63–64
- Wang H S, 1930. The geology in eastern Shantung. *Bull Geol Soc China*, 9(1): 79–91
- Wang Q, Zhao Z K, Wang X L et al., 2013a. New forms of dictyoolithids from the Tiantai Basin, Zhejiang Province of China and a parataxonomic revision of the dictyoolithids. *Vert Palasiat*, 51(1): 43–54
- Wang Q, Wang X L, Zhao Z K et al., 2013b. New turtle egg fossil from the Upper Cretaceous of the Laiyang Basin, Shandong Province, China. *An Acad Bras Cienc*, 85(1): 103–111
- Wang X L, Wang Q, Wang J H et al., 2010. An overview on the Cretaceous dinosaurs and their eggs from Laiyang, Shandong Province, China. In: Dong W ed. *Proceedings of the Twelfth Annual Meeting of the Chinese Society of Vertebrate Paleontology*. Beijing: China Ocean Press. 293–316
- Wang X L, Wang Q, Jiang S X et al., 2012. Dinosaur egg faunas of the Upper Cretaceous terrestrial red beds of China and their stratigraphical significance. *J Stratigr*, 36(2): 400–416
- Wiman C, 1929. Die Kreide-Dinosaurier aus Shantung. *Paleont Sin Ser C*, 6(1): 1–67
- Yan J, Chen J F, 2005. *Clinopyroxene megacrysts* in the Late Mesozoic basalts from Daxizhuang, Jiaozhou. *J Anhui Univ Sci Technol Nat Sci*, 25(3): 9–13
- Young C C, 1954. Fossil eggs from Laiyang, Shantung, China. *Acta Palaeontol Sin*, 2(4): 371–388
- Young C C, 1958. The dinosaurian remains of Laiyang, Shantung. *Palaeontol Sin, New Ser C*, 16: 1–138
- Young C C, 1960. Fossil footprints in China. *Vert Palasiat*, 4(2): 53–66
- Young C C, 1965. Fossil eggs from Nanshiung, Kwangtung and Kanchou, Kiangsi. *Vert Palasiat*, 9(2): 141–165
- Young C C, Wang C Y, 1959. The new collection of dinosaur fossil from Laiyang, Shantung. *Vert Palasiat*, 1(1): 53–54
- Zhang J F, 1992. Late Mesozoic insects and ecological characteristics in Shandong, Laiyang. *Chin Sci Bull*, 1992, 37(5): 431–434
- Zhang J L, Wang X L, 2012. Summary on the morphology and function of the cranial crests of hadrosaurid dinosaurs. *Science (KEXUE)*, 64(3): 24–28
- Zhang J L, Wang X L, Wang Q et al., in press. A new saurolophine hadrosaurid (Dinosauria: Ornithopoda) from the Upper Cretaceous, Shandong, China. *An Acad Bras Cienc*
- Zhao X J, 1962. A new genus of Psittacosauridae from Laiyang, Shantung. *Vert Palasiat*, 6(4): 349–364
- Zhao X J, Li D J, Han G, 2007. *Zhuchengosaurus maximus* from Shandong Province. *Acta Geosci Sin*, 2: 111–122
- Zhao X J, Wang K B, Li D J, 2011. *Huaxiaosaurus aigahtensis*. *Geol Bull China*, 30: 1671–1688
- Zhao Z K, 1975. The microstructure of dinosaurian eggshells of Nanhsiung Basin, Guangdong Province. *Vert Palasiat*, 13(2): 105–117
- Zhao Z K, 1979. The advancement of research on the dinosaurian eggs in China. In: IVPP, NIGP eds. *Mesozoic and Cenozoic Redbeds in Southern China*. Beijing: Science Press. 330–340
- Zhen S N, 1976. A new species of hadrosaur from Shandong. *Vert Palasiat*, 14(3): 166–168
- Zhou C F, 2010. A possible azhdarchid pterosaur from the Lower Cretaceous Qingshan Group of Laiyang, Shandong, China. *J Vert Paleont*, 30(6): 1743–1746